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# State-of-the-Art Offshore Power System in the German Bight and Technical Mid-Term Expansion Options

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**Energy Economy and Grid Operation**
**Transmission Grids**

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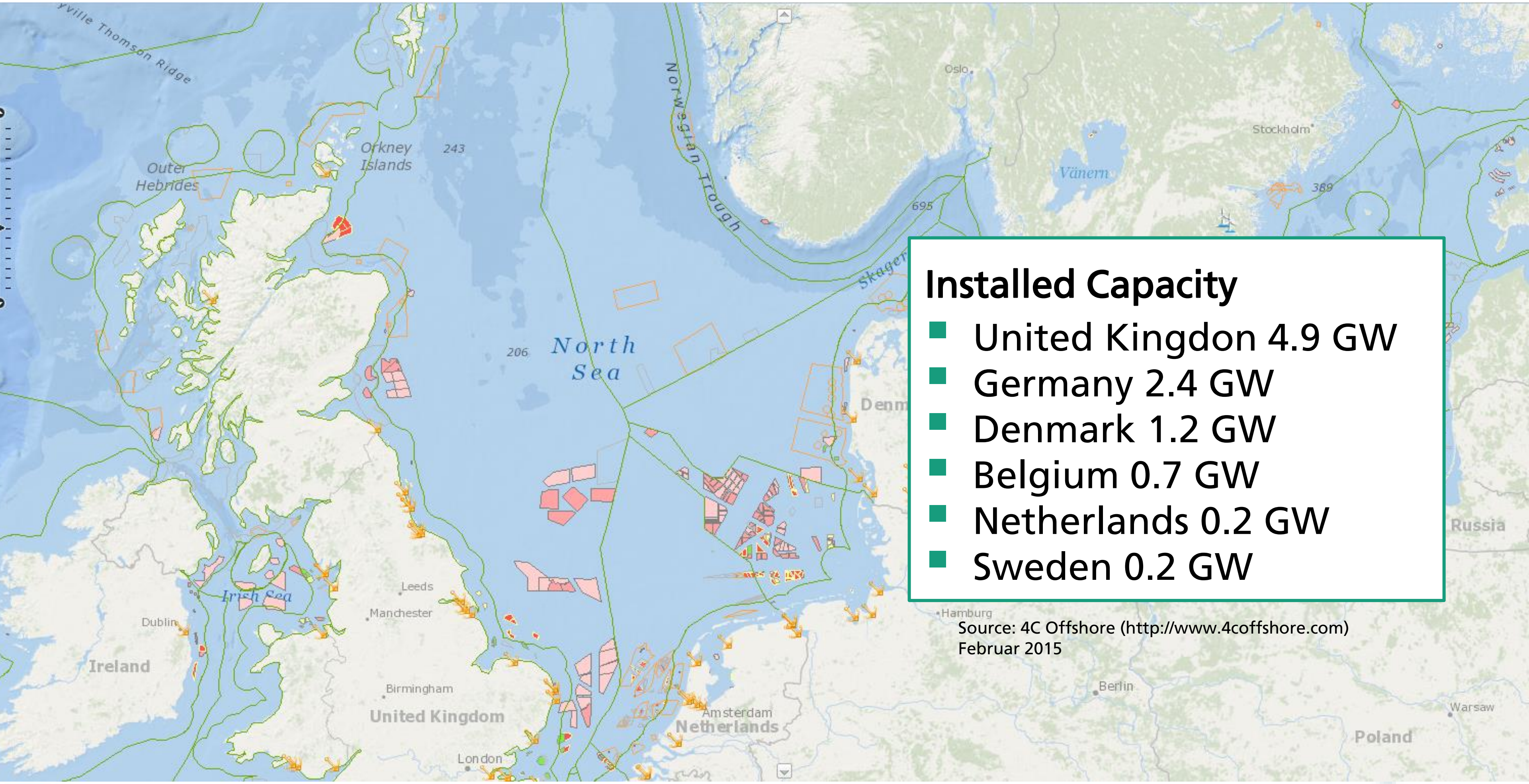
- North Sea Overview
- Cluster Concept for Offshore Connections
- Transmission Technology
- Status in the German Bight
- Redundancy Options
- Reliability Analysis
- North Sea Offshore Network

# North Sea Overview




## Installed Capacity

- United Kingdon 4.9 GW
- Germany 2.4 GW
- Denmark 1.2 GW
- Belgium 0.7 GW
- Netherlands 0.2 GW
- Sweden 0.2 GW

Source: 4C Offshore (http://www.4coffshore.com)
Februar 2015



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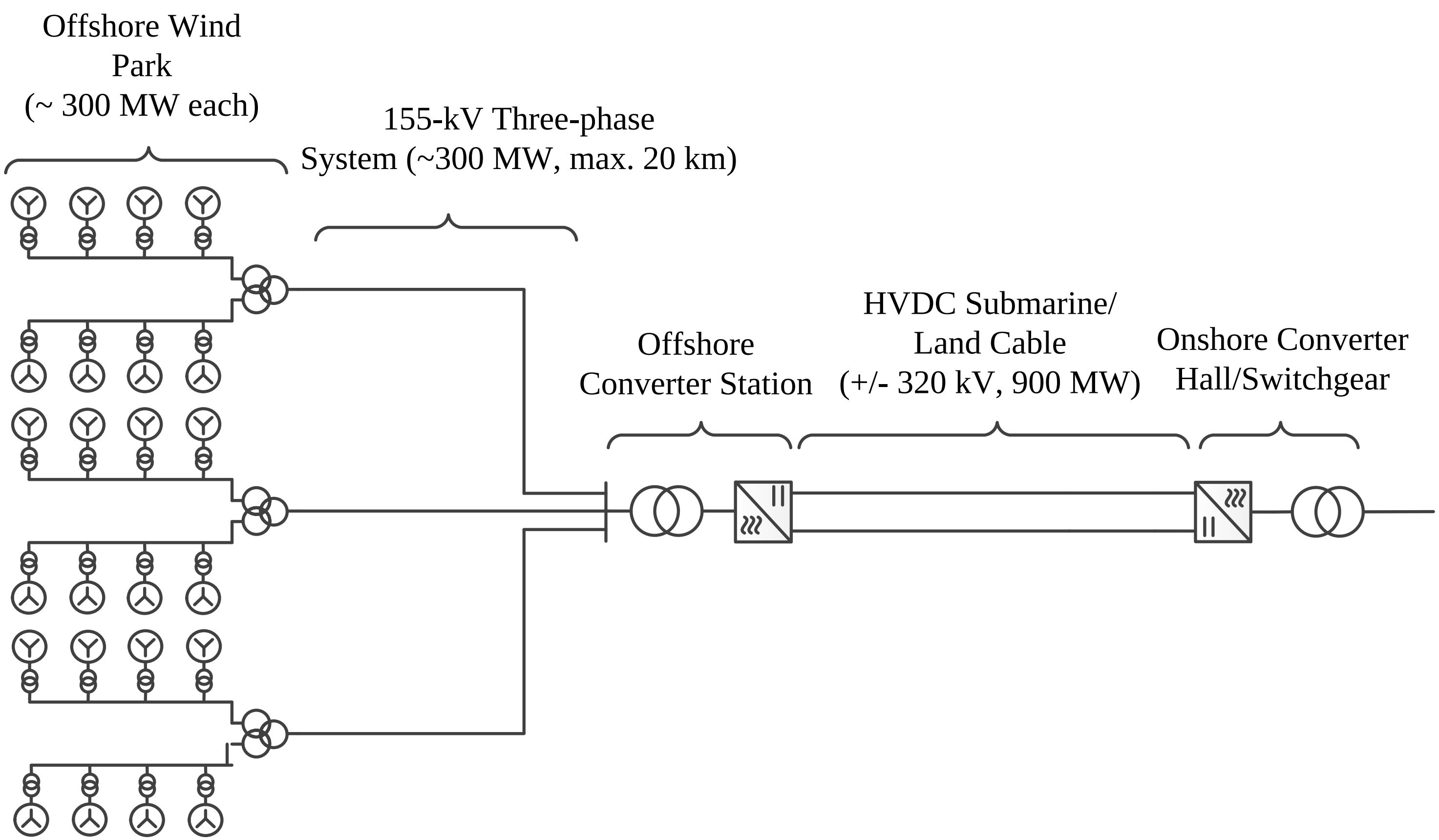
# The Cluster Concept for Offshore Connections



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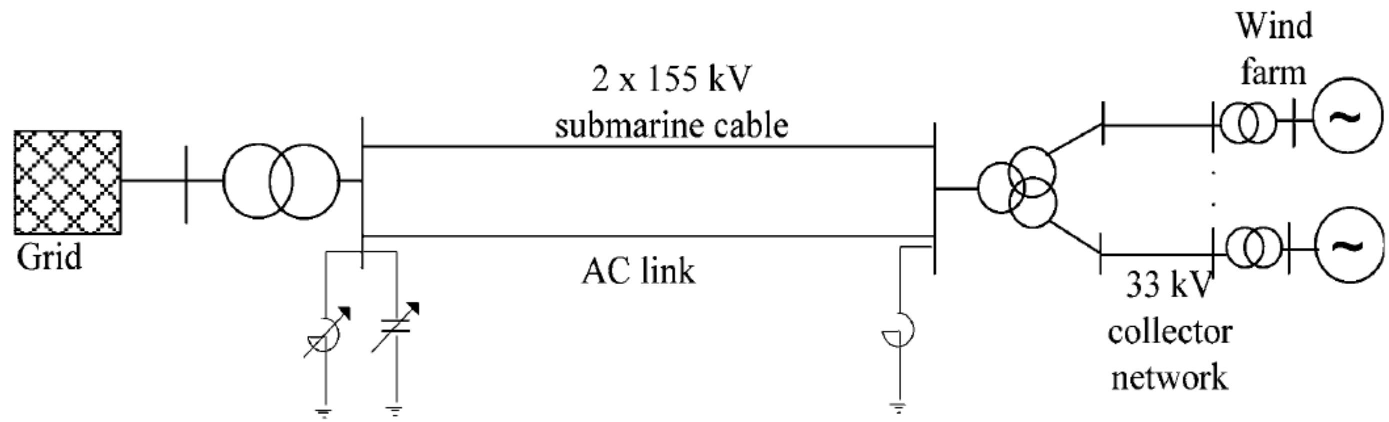
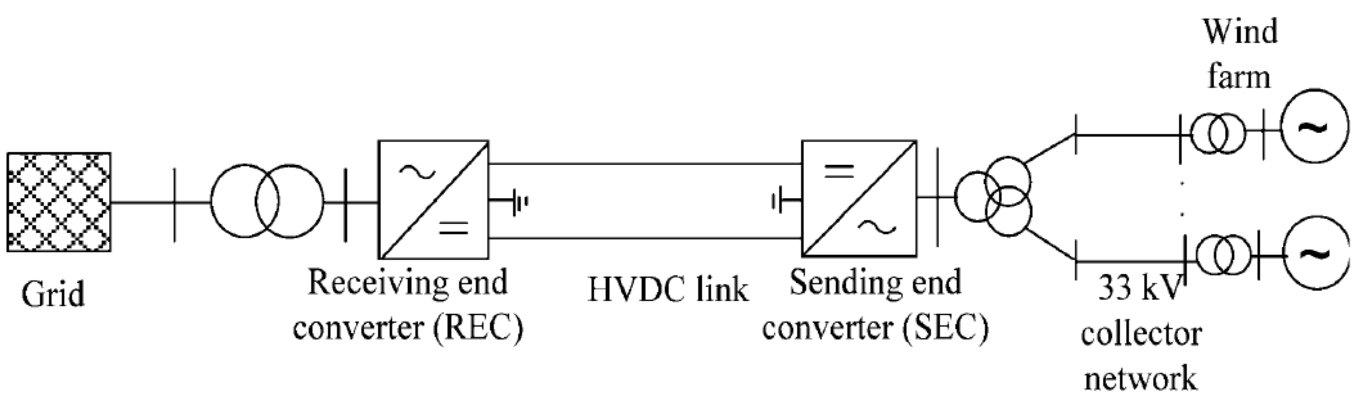
# Connection to Shore




Source:
Dr. Feltes, RWE Innogy

# Submarine Cables

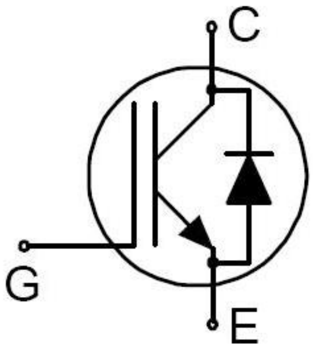
- HVAC
  - Three-Core
  - Single-Core
- HVDC
  - Oil-Paper
  - XLPE

Source:
ABB

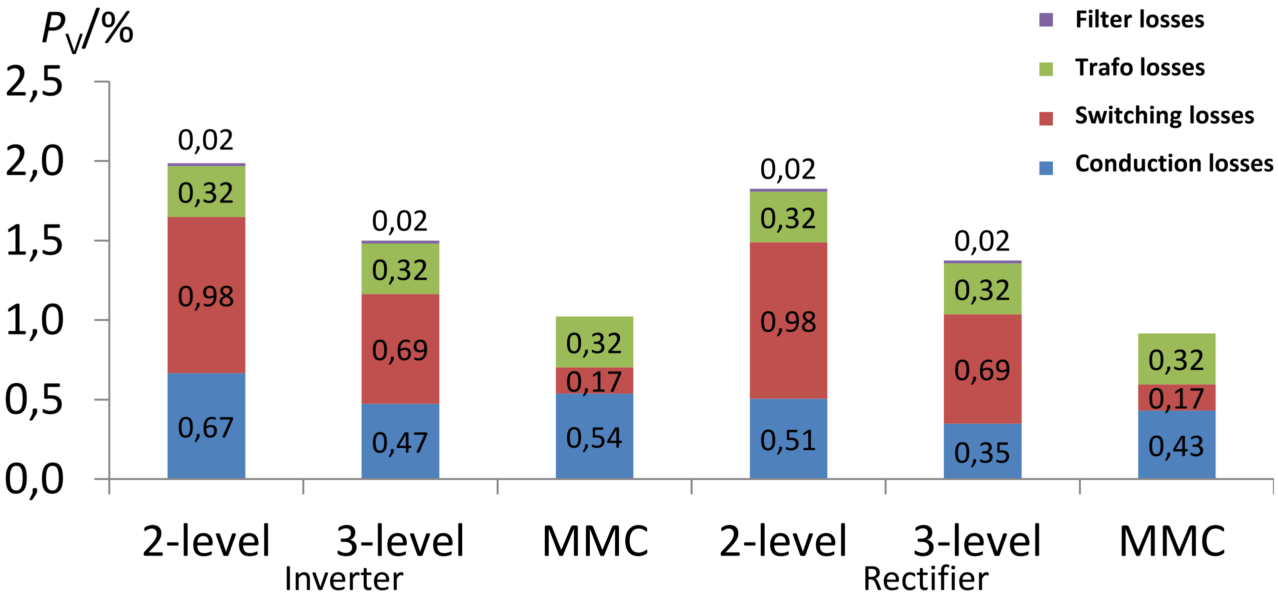
# HVDC Devices

IGBT Technology (currently up to 6,5 kV)

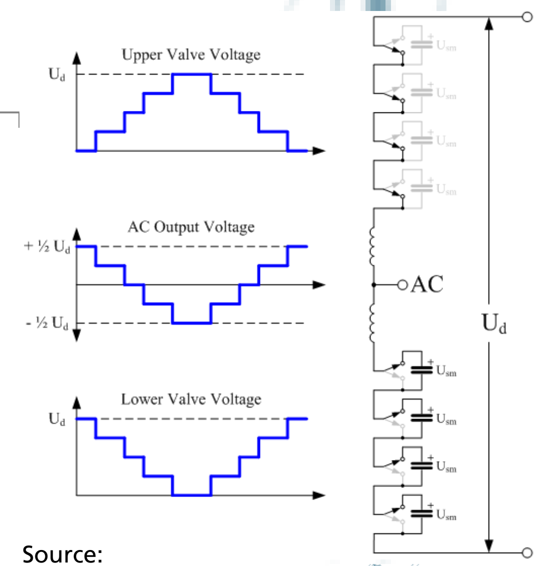

- IGBT Module
  - Soldered bond contact
  - Infineon
  - Misubishi
  - ABB
  - Semikron
  - …
- Press-Pack IGBT
  - Ceramic bond
  - Toshiba
  - Westcode/IXYS
  - ABB
  - Fuji
  - …



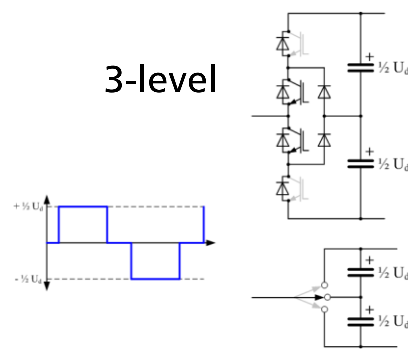
# HVDC Converter Topologies

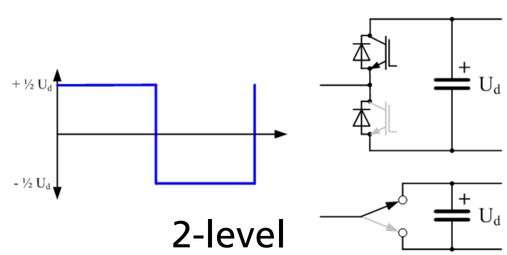



MMC




3-level





2-level

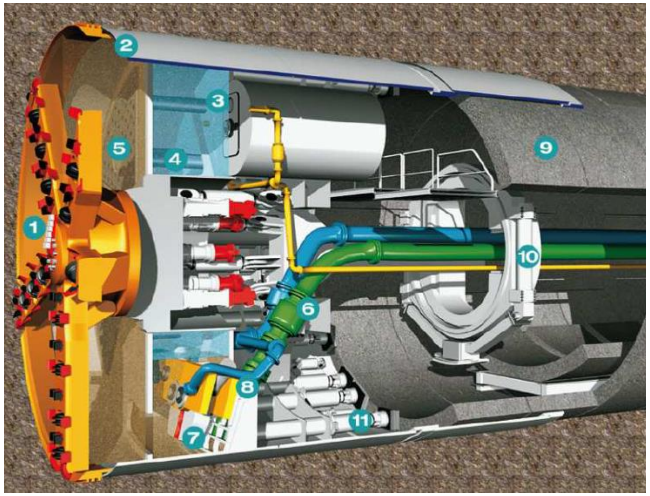
Source:
Creative Common Licence

# Gas Insulated Lines (GIL)

- 400 kV
- > 2000 MVA
- Low Losses
- SF6 gas insulation
- Self Healing after fault
- > 300km distances
- No outer magnetic field
- No compensation required

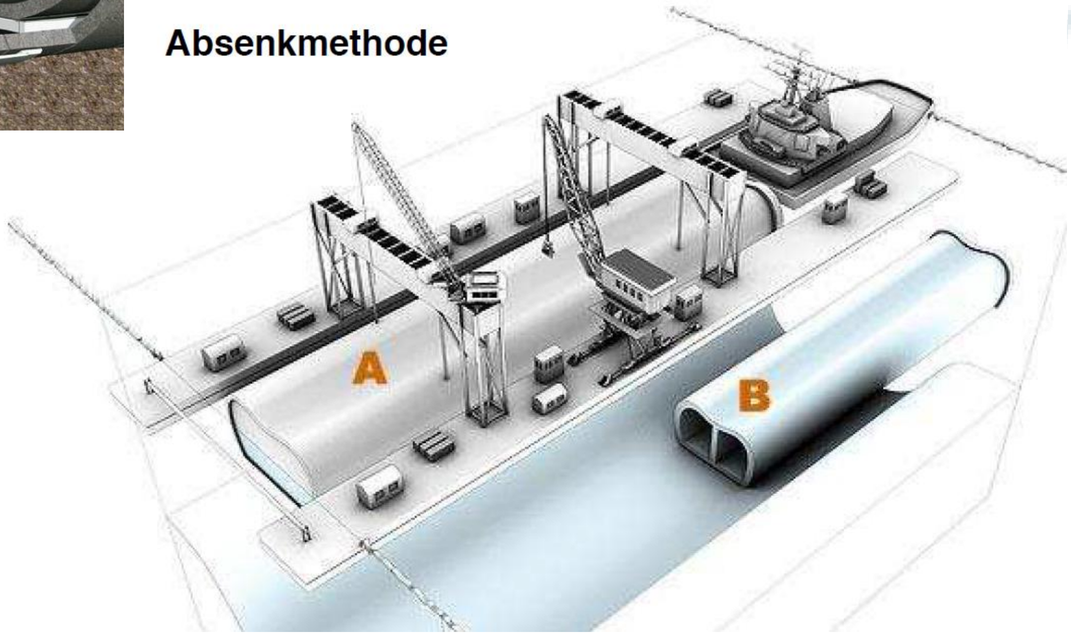
Source:
Prof. Hofmann, University Hannover

# Gas Insulated Lines (GIL)

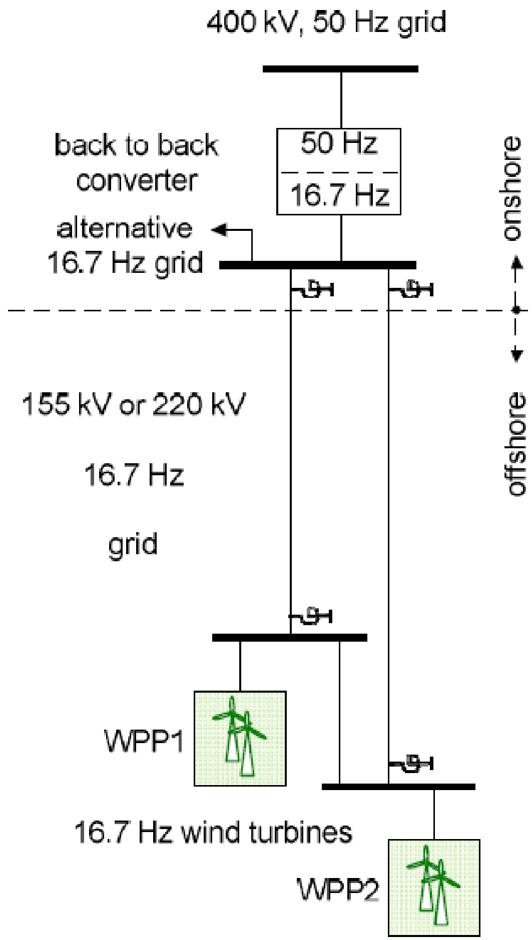


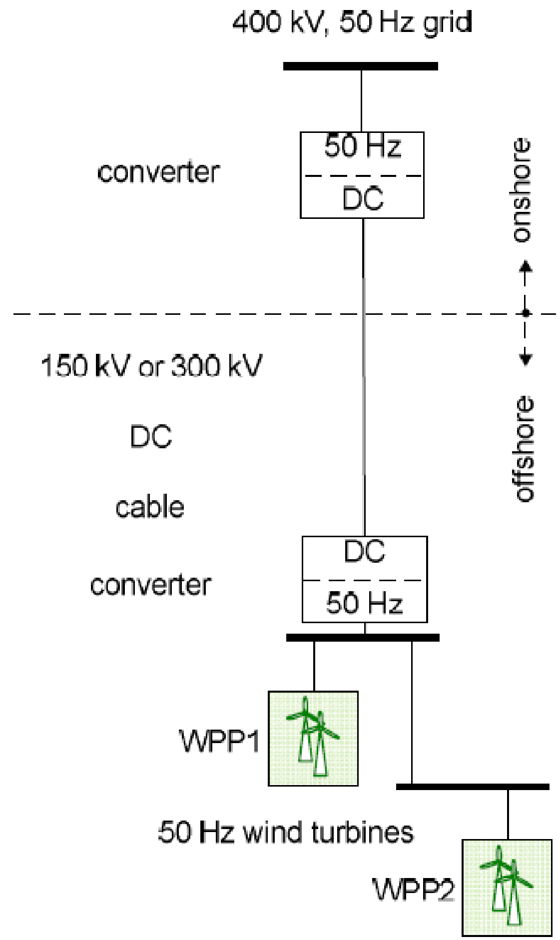

Source:
Prof. Hofmann, University Hannover

Absenkmethode



# Low Frequency AC Transmission




Source:
Prof. Erlich, University Duisburg-Essen



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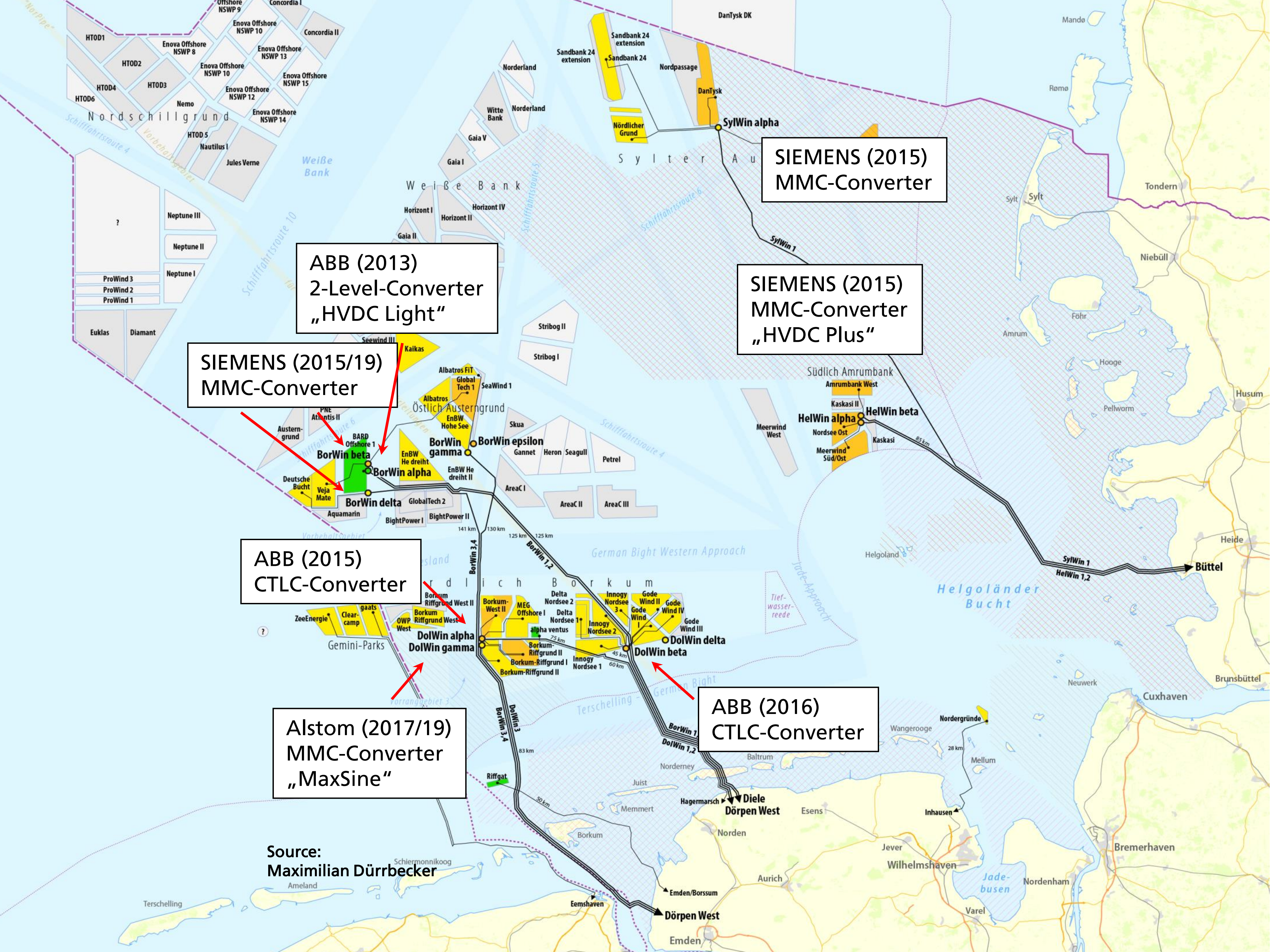


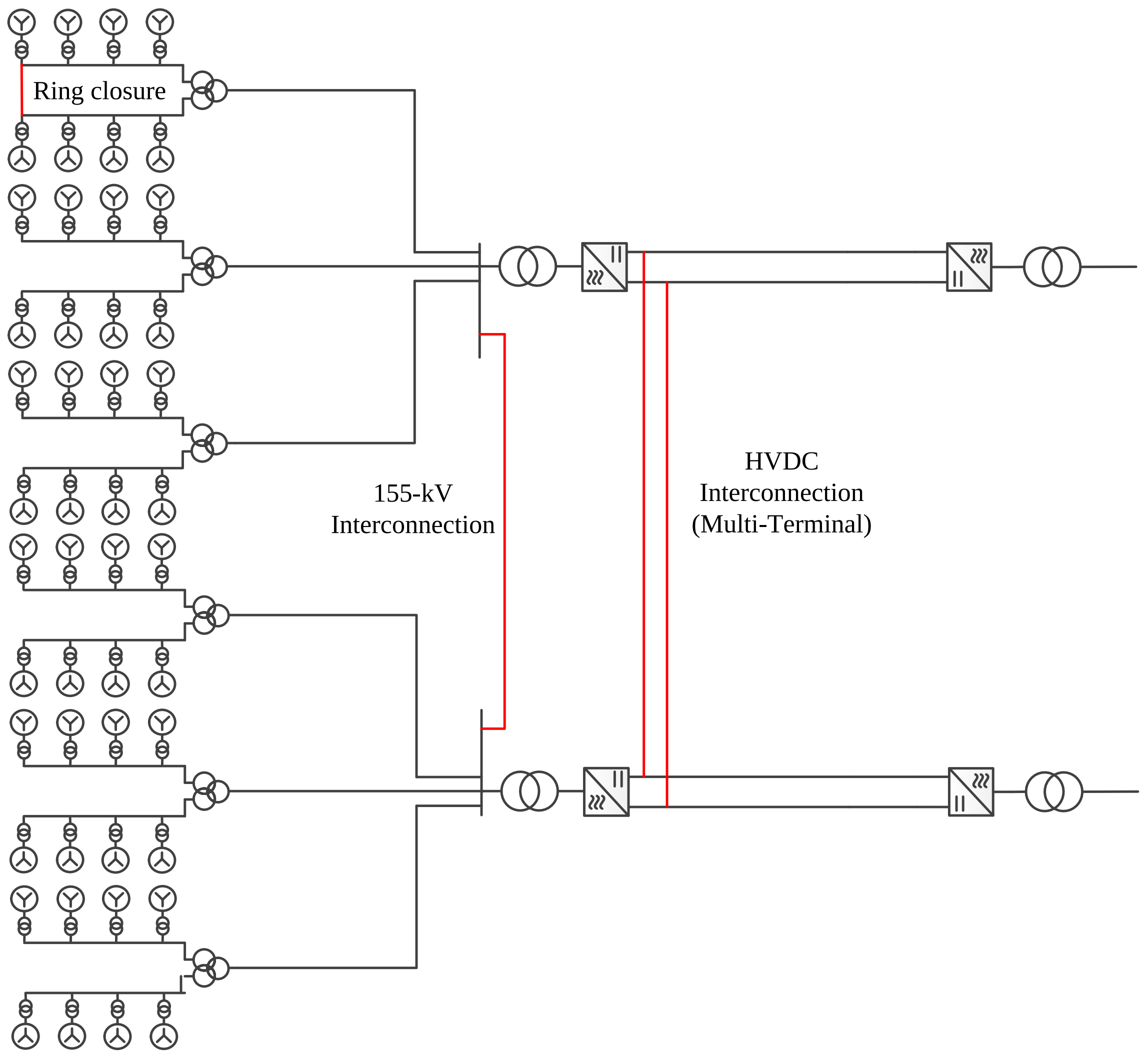
SIEMENS (2015)
MMC-Converter
SIEMENS (2015)
MMC-Converter
„HVDC Plus"
ABB (2013)
2-Level-Converter
„HVDC Light"
SIEMENS (2015/19)
MMC-Converter
ABB (2015)
CTLC-Converter
ABB (2016)
CTLC-Converter
Alstom (2017/19)
MMC-Converter
„MaxSine"
SylWin alpha
SylWin 1
HelWin alpha
HelWin beta
SylWin 1
HelWin 1,2
Büttel
BorWin alpha
BorWin beta
BorWin gamma
BorWin delta
BorWin epsilon
BorWin 1,2
BorWin 3,4
DolWin alpha
DolWin gamma
DolWin beta
DolWin delta
DolWin 1,2
DolWin 3
Diele
Dörpen West
Hagermarsch
Emden/Borssum
Dörpen West
Nordschillgrund
Weiße Bank
Östlich Austerngrund
Nördlich Borkum
Helgoländer Bucht
German Bight Western Approach
Gemini-Parks
DanTysk
Sandbank 24
Nordpassage
Helgoland
Cuxhaven
Bremerhaven
Wilhelmshaven
Emden
Husum
Tondern
Source:
Maximilian Dürrbecker

# North Sea Development Stage, German Bight

- In Operation (DC)
  - BorWin 1, 400 MW, 2010
  - BorWin 2, 800 MW, 2015
  - DolWin 1, 800 MW, 2015
  - HelWin 1, 576 MW, 2015
  - HelWin 2, 690 MW, 2015
  - SylWin 1, 864 MW, 2015
- In Operation (AC)
  - alpha ventus, 62 MW
  - Riffgat, 113 MW
- Construction commisioned
  - BorWin 3, 900 MW, 2019
  - DolWin 2, 916 MW, 2016
  - DolWin 3, 900 MW, 2017
  - Nordergründe (AC) 111 MW
- Planned (DC)
  - BorWin 4, 900 MW, 2019
  - BorWin 5, 900 MW, 2023
  - DolWin 4, 900 MW, 2025
  - SylWin 2, 900 MW, 2024

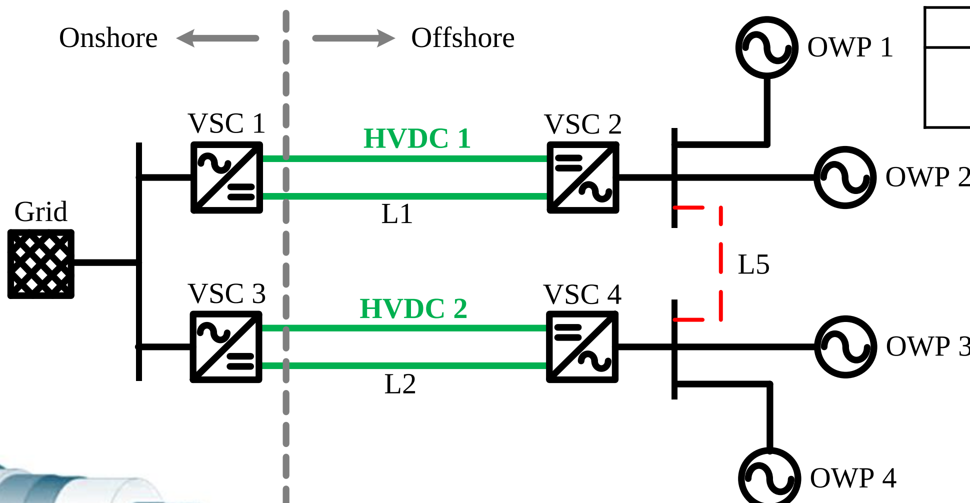
Source:
TenneT Offshore GmbH

# Redundancy Options



# Reliability Analysis for Parallel HVDC – Case A

| States | Probabilities | h/year | Yield without outage [MWh] | Yield with outage [MWh] Without line (Base Case) | 300 MW line | 450 MW line |
|---|---|---|---|---|---|---|
| No outage | 95,028% | 8324,44 | 7491992,6 | 7491992,6 | 7491992,6 | 7491992,6 |
| One HVDC out of service | 4,859% | 425,61 | 383047,4 | 191523,7 | 319206,2 | 383047,4 |
| Two HVDC out of service | 0,063% | 5,48 | 4933,9 | 0 | 0 | 0 |
| HVDC and AC Interconnection out of service | 0,051% | 4,47 | 4026,4 | 2013,2 | 2013,2 | 2013,2 |
| **Sum** | 1,00 | 8760,00 | 7.884.000,33 | 7.685.529,52 | 7.813.211,99 | 7.877.053,22 |
| | | | Difference (MWh) | 0,00 | 127.682,47 | 191.523,71 |
| **Energy costs €/MWH** | **100** | | Cost savings | 0,00 € | **12.768.247,06 €** | **19.152.370,59 €** |




| iterest rate | 8% | |
|---|---|---|
| savings (20 years) | **125,4 Mio €** | **188,0 Mio €** |
| savings (25 years) | **136,3 Mio €** | **204,4 Mio €** |

**450 MW installed (each OWP)**
**Ø 50% in-feed**



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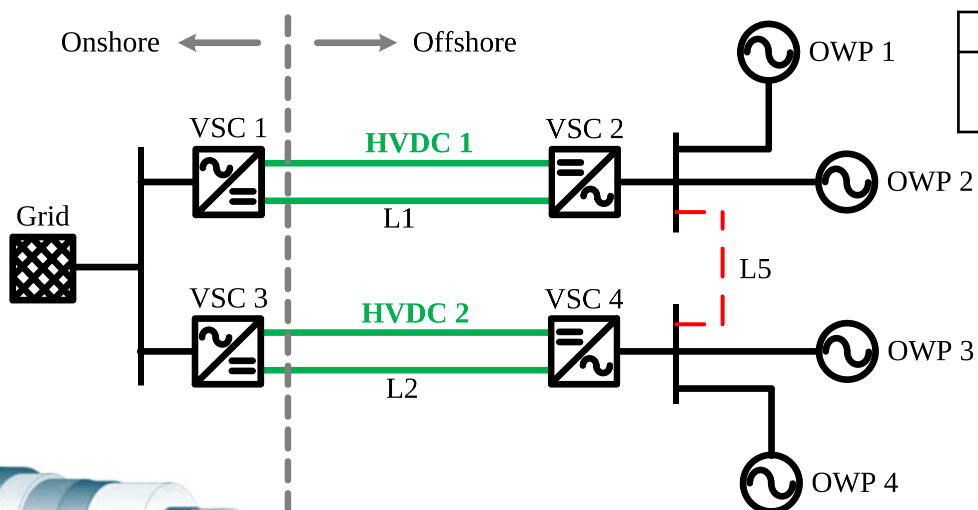
# Reliability Analysis for Parallel HVDC – Case B

| States | Probabilities | h/year | Yield without outage [MWh] | Yield with outage [MWh] Without line (Base Case) | 300 MW line | 450 MW line |
|---|---|---|---|---|---|---|
| No outage | 95,028% | 8324,44 | 5993594,1 | 5993594,1 | 5993594,1 | 5993594,1 |
| One HVDC out of service | 4,859% | 425,61 | 306437,9 | 153219,0 | 280901,4 | 306437,9 |
| Two HVDC out of service | 0,063% | 5,48 | 3947,1 | 0 | 0 | 0 |
| HVDC and AC Interconnection out of service | 0,051% | 4,47 | 3221,1 | 1610,6 | 1610,6 | 1610,6 |
| **Sum** | 1,00 | 8760,00 | 6.307.200,26 | 6.148.423,61 | 6.276.106,08 | 6.301.642,58 |
| | | | Difference (MWh) | 0,00 | 127.682,47 | 153.218,96 |
| **Energy costs €/MWH** | **100** | | Cost savings | 0,00 € | **12.768.247,06 €** | **15.321.896,47 €** |



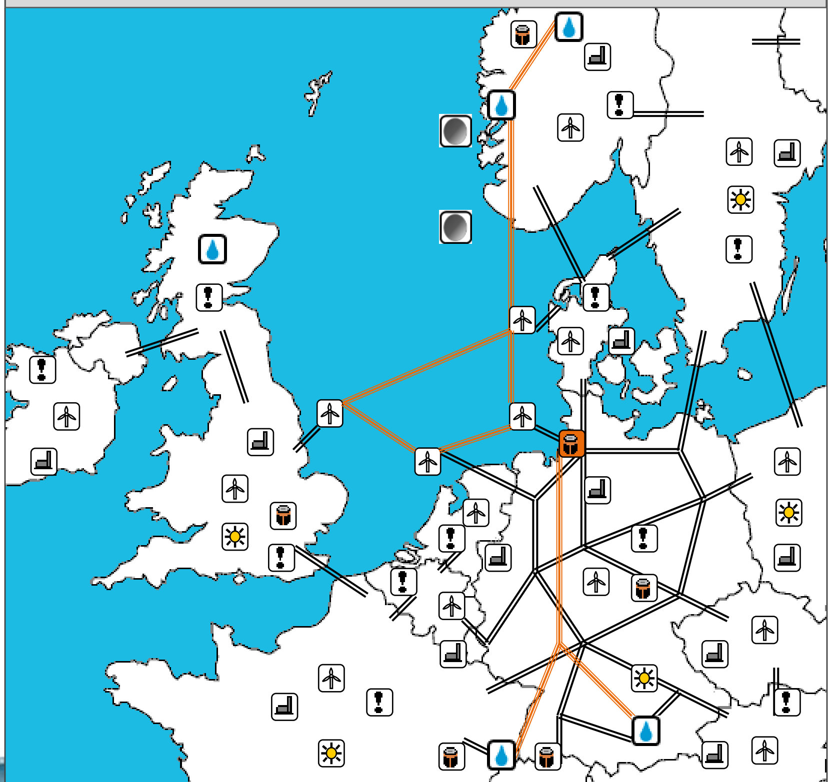

| iterest rate | 8% | |
|---|---|---|
| savings (20 years) | **125,4 Mio €** | **150,4 Mio €** |
| savings (25 years) | **136,3 Mio €** | **163,6 Mio €** |

**450 MW installed (each OWP)**
**Ø 40% in-feed (3500 full-load hours)**

# North Sea Offshore Network (NSON)

Eurpean Commision[1)] treats offshore power system as priority corridor between North and Central Europe

North Sea Offshore and Storage Network (NSON)



**NSON could be first step towards european „SuperGrid“ (Overlay-Network)**

**NSON project objectives:**

- **Analysis of different market and power system options**
- **Quantifiy the effect on German and European energy supply system**
- **Quantifiy the effect on power system infrastructure**
- **New developments in mathematical optimization methods for power system planning and operation purposes**

[1)] European Union (2011): Energy infrastructure priorities for 2020 and beyond. A Blueprint for an integrated European energy network.

# NSON Potential Benefits

| | | |
|---|---|---|
| NSON as additional power system expansion in the north sea region | Improvement of Interconenction between load centers | Security of supply |
| | Reduced imports of fossil fuels | |
| | Transmission of offshroe wind energy to load centers | |
| | Avoiding of transmission system congestions | |
| | Increase of exchange capacit between countries, increase trading and competition | Market and competition |
| | Containment of peak prices | |
| | Driving force for standards for offshore wind and suppliers | |
| | Beneficial for integration of offshore wind capacity | Integration of renewable energy |
| | Power balancing due to spatial extension | |
| | Integration of scandinavian hydroeletric capacities | |
| | Integration of offshore storage technologies | |
| | Contribution to $CO_2$ reduction | |



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